Approaches to the Development of an Automated Control System for the Adaptation of Agricultural Areas under the Changing Greenhouse Effect

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Abstract: This paper deals with the main aspects of automated management of the adaptation of agricultural areas under the changing greenhouse effect. The authors explore the approaches to the construction of such an automated control system (ACS), the structure and functions of which would ensure the scientific validity and effectiveness of management decisions, due to the implementation of agro-ecological and natural-agricultural zoning of territories using data mining, GIS, and 3D modeling. Functional and structural models of the automated control system and the control object have been developed.

Keywords: automated control system, agricultural area adaptation management, greenhouse effect, modeling, intelligent decision support.

One of the relevant and widely discussed global environmental problems of modern society is the greenhouse effect (GHE), the impact of which on the environment increases with the development of production and agricultural technologies, as well as with a decrease in forest areas. The main hazard is the concentration of greenhouse gases (GHGs) in the atmosphere, primarily carbon dioxide (CO_2), which retard thermal radiation and contribute to climate change: temperature increase, ozone layer destruction, etc. However, there is another side, which is extremely important for such countries, most of whose territories belong to risky farming zones (Russia, Poland, Czech Republic, Germany, Canada), associated with the effect of PE on the humus state of the soil and an increase in the photosynthetic activity of plants. Temperature, soil moisture, solar radiation flux, atmospheric and soil CO_2 concentration are a set of parameters that determine the capabilities and productivity of ecosystems and affect the efficiency of agriculture [6].

A number of studies reported a positive effect on crop yields with an increase in the concentration of CO^2 in the atmosphere [1, 2, 3]. According to the results of the analysis of research data, on average for all species, the increase in yield and dry matter of young plants was 26% and 40%, respectively. It was found that the development of young plant biomass in most cases responded more strongly to high CO_2 content. According to [1], the increase in grain yield with a doubling of CO_2 concentration is almost twice as high as the gain in biomass (36% and 20%).

The review of international literature has shown a recent increase in the number of scientific studies on the following topics:

– development and approbation of production technologies and modernization of technological processes in the power, agriculture, and industrial sector, ensuring the reduction of atmospheric emissions of major greenhouse gases [8];
– creation and implementation of alternative energy sources [9];
– calculation and forecasting of greenhouse gas concentrations from both man-made and natural sources [6, 7];
– modeling of climate change [4, 5].

However, there are no research results in the development and updating of the agricultural sector of a system that allows us both to quantitatively and spatially assess and predict the level of greenhouse gas emissions, and form adaptation scenarios that determine the most effective conditions for sowing crops in terms of yield (the location of the territory, the area of crops, the specifics of the culture itself, the expected effect).

The formation and evaluation of the effectiveness of such adaptation scenarios for the agricultural industry are inherently associated with the collection, processing, and analysis of intensive flows of multiple heterogeneous information, the need to consider sources distributed over large areas and the participation of living organisms in production processes. This determines the need to develop and use a set of mathematical and situational models, specialized algorithms and methods for assessing and predicting the development of situations using the capabilities of several digital technologies simultaneously (artificial intelligence, Big Data, virtual and augmented reality technologies, GIS, etc.).

The team of authors proposes to develop an automated control system for the adaptation of agricultural territories under the changing greenhouse effect, which will ensure the determination of the optimal parameters of natural-agricultural and agro-ecological zoning of the studied territories, their qualitative and quantitative structure.

The corresponding conceptual chart of territory zoning to increase crop yields in the changing GHE is shown in Figure 1.

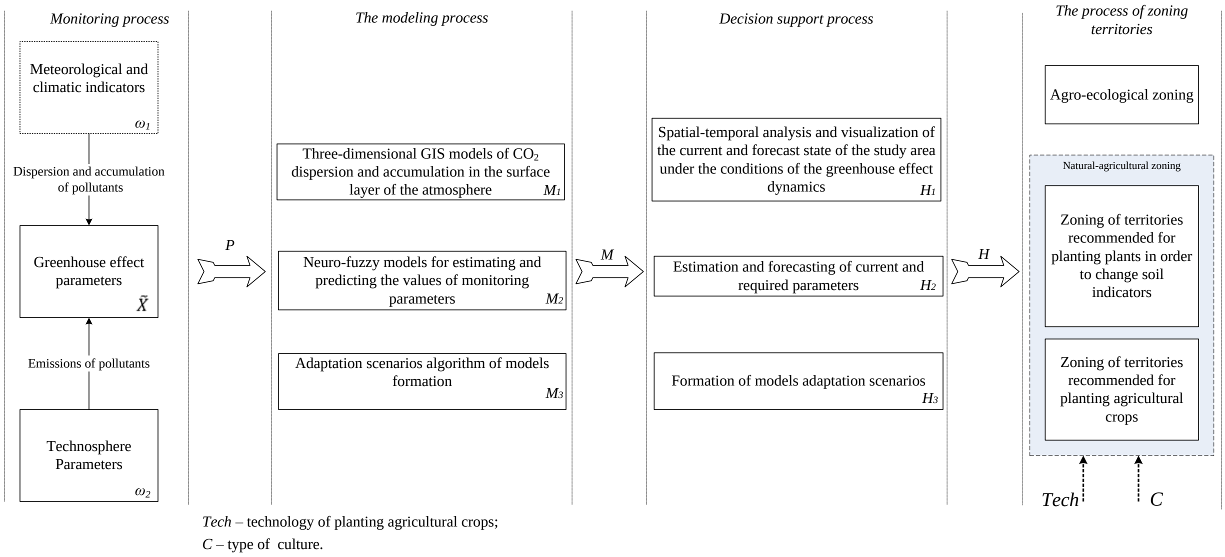

Figure 1 – A chart of adaptive territory zoning to increase crop yields in the changing GHE using digital technologies

This chart is composed of the following processes:

– Monitoring process, where $P = \{\omega_1, \omega_2, \widetilde{X}\}$, ω_1 is the most variable, controlled, but unmanageable meteorological factor, ω_2 is technosphere parameters that determine the power and patterns of atmospheric emissions of pollutants; $\widetilde{X}$ is parameters of the greenhouse effect, which are formed under the influence of meteorological and man-made parameters (air temperature, heat supply of soil and CO_2 concentration in the surface layer of the atmosphere), can be represented as $\widetilde{X} = f(\omega_1, \omega_2)$;

– Modeling process, where $M = \{M_1, M_2, M_3\}$: 3D GIS models (M_1) are built based on monitoring data (P); neuro-fuzzy models (M_2) that determine cause-and-effect relationships $g\{\omega_1, \omega_2, \widetilde{X}\}$; algorithm for the formation of models of adaptation scenarios (M_3).

– Decision support process, where $H = \{H_1, H_2, H_3\}$, which provides processing of information into a form suitable for making managerial decisions. At this level, based on the results of complex data mining, models of adaptation scenarios for zoning the studied territories are formed.

– Territory zoning process; implementation of specific control actions, namely the determination of the spatial and structural parameters of the territory for planting a certain crop (C) using the most optimal planting and processing technology under the given conditions (Tech). It should be noted that places with high CO_2 concentration and poor soil indicators can be recommended to plant carbonic plants to absorb and accumulate CO_2 in the soil, which contributes to the enrichment of the humus layer and further use of the territory for agricultural purposes.

Thus, the traditional approach of zoning agricultural areas is being modernized in order to increase crop yields. This requires a fundamental change in the yield management system, considering the adaptation of territories to the changes in GHE when using digital technologies. Figures 2 and 3 present the corresponding IDEF0-built functional models for building a management system for the adaptation of agricultural territories to the changing GHE. The chart shows that, unlike the traditional approach, such mechanisms have been introduced for the implementation of the control process as mathematical, simulation, situational models, and appropriate software (SW).

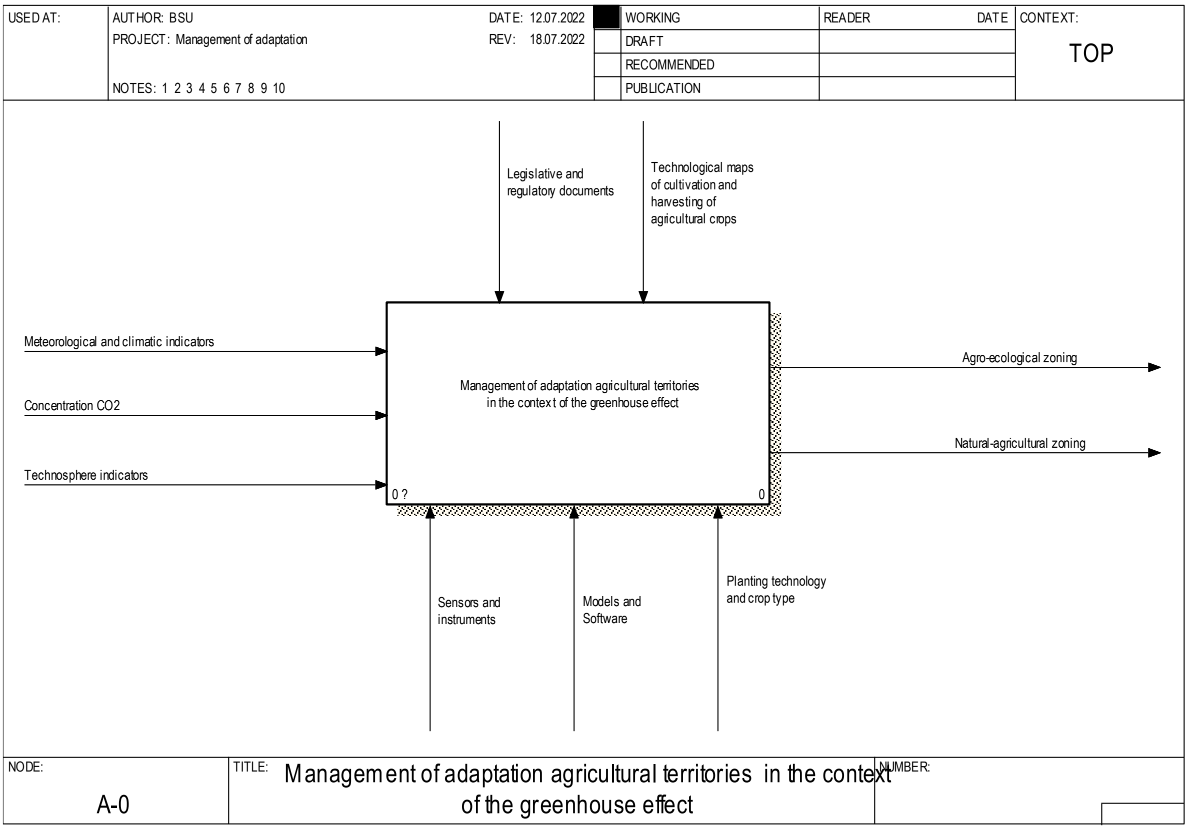

Figure 2 - A context chart of managing the adaptation of agricultural territories to the changing GHE

Considering the complexity of managing the adaptation of agricultural territories, Figure 3 shows the decomposition of the process to display a more detailed structure of the sub-processes that occur during the task being solved. The chart of the figure shows the introduction of a specialized block of intelligent decision support, in which, using the above models (M_1, M_2) and a specialized algorithm (M_3), spatio-temporal analysis, assessment and forecasting of the current and forecast state of the studied territories are carried out and models of possible for the implementation of adaptation scenarios for agro-ecological and natural-climatic zoning of the studied agricultural area are fromed.

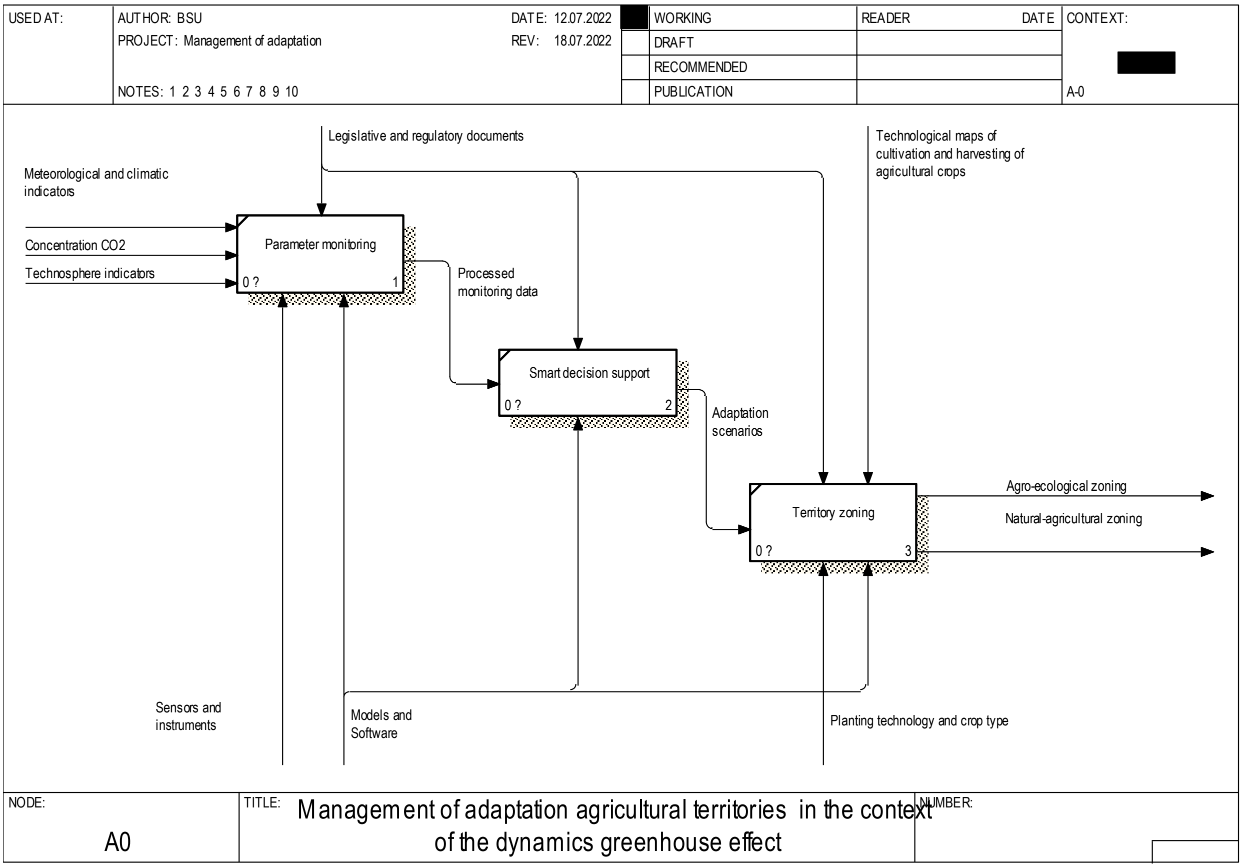

Figure 3 - Decomposition of the context chart of managing the adaptation of agricultural territories to the changing GHE

The functional modeling made it possible to develop a generalized structural model of an automated control system for the adaptation of agricultural territories under the changing GHE, which is schematically shown in Figure 4.

This ACS consists of the following main subsystems:

– Control object – adaptation of agricultural areas under the changing GHE – the state of which is described by the set X;
– Monitoring system – collects and pre-processes data (P);
– Intelligent decision support system – evaluates, predicts, performs spatio-temporal analysis, and generates models of alternative control scenarios (H);
– Control subsystem – develops a set of control actions on the control object U, while Y is feedback that provides the results of the implementation of specific control scenarios;
– Q is the measured parameter of external influences.

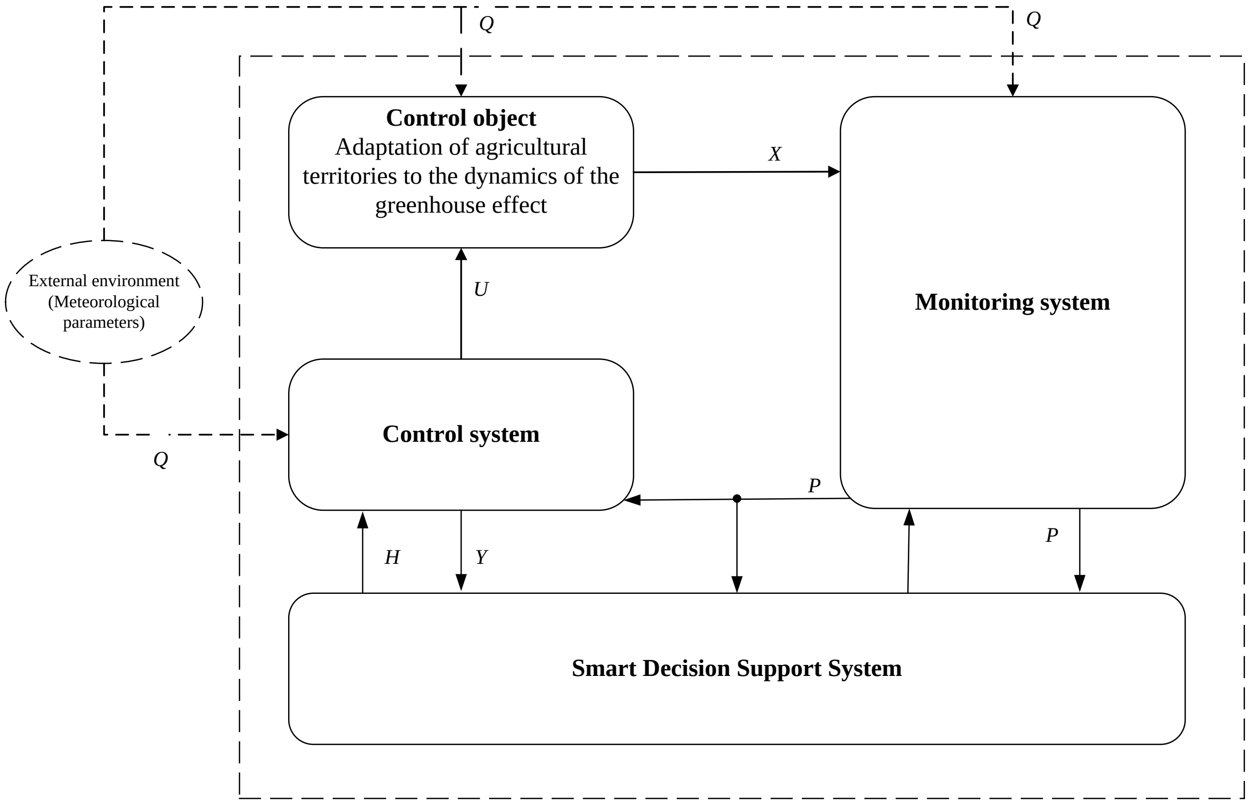

Figure 4 - A generalized model of an automated control system for the adaptation of agricultural areas under the changing greenhouse effect

To ensure the effective functioning of the introduced intelligent decision support system, it must be filled with a set of models and algorithms from the set M (Figure 1).

The set-theoretic approach allows us to represent the control object of the studied automated control system in the form of the following system:

$A_{oy} = \langle S_{oy}, Q, X, F_{oy}, V_{oy} \rangle$,

where S_{oy}={s_{oy}} the set of elements of the control object.

The external influence on the set S_{oy} describes the input parameters Q, which include two main sets: U - control actions and ω - external influences, where $\omega = \{\omega_1, \omega_2\}$, the set Q takes the form, Q = {U, ω}, где U = {U_{cp},U_{cc}}. . External factors are: meteorological, natural, and climatic indicators and parameters of the technosphere.

U_{cp} – territorial zoning of agricultural territories for the greatest positive effect from the CO_2 concentration accumulated in the surface layer of the atmosphere by agricultural plants during photosynthesis.

U_{cc} – territorial zoning of agricultural areas in relation to the concentration of CO_2 in order to mineralize the humus layer and prepare land for further use in agricultural activities.

ω_1 are meteorological and natural-climatic parameters of the study area.

ω_2 are technosphere parameters that can influence the study area.

X = {L, Z} is a set of parameters that describe the state of the elements in S_{oy}: L is a set characterizing the volume (quantity of production per unit area) and quality of the harvested crop (concentration of nutrients); Z = {Z_{cp}, Z_{cc}}, where Z_{cp} is the set of states of agricultural territories: technological and technical parameters, volumes of resources consumed and CO_2 emissions in the process of agricultural production; Z_{cc} is a set of states of agricultural territories: technological and technical parameters, the volume of CO_2 absorbed and emitted into the atmosphere during the preparation of agricultural territories.

F_{oy}={f_{oy}} is a set of of mappings on S_{oy}, Q, X;

F_{oy}: $(S_{oy}, Q, X) \rightarrow X$.

V_{oy}={v_{oy}} is a set of relations over the elements S_{oy}, Q, X;

V_{oy}: (S_{oy}, Q, X).

The sets S_{oy}, Q, X are formed depending on the GHG concentration, meteorological and climatic conditions in the territory under consideration.

To build a modified model of the control object, it is proposed to divide the process of crop production under the changing GHE into three components:

– Collection of products - s_{cy} - a set of components that determine the process of collecting crop products and assessing yields.
– Cultivation of land and agricultural plants - s_{cp} - considering the intellectual analysis of monitoring data.
– CO_2 sequestration - s_{cc} - organization and implementation of the process of carbon accumulation in the upper soil layer to improve soil indicators, also based on estimates and forecasts.

Thus, the control object as a system includes three main subsystems $S_{oy} = \{s_{cy}, s_{cp}, s_{cc}\}$, which allow adapting agricultural areas to obtain the largest amount of crop relative to the concentration of GHGs in the surface layer of the atmosphere, thanks to control actions that change the parameters of "Cultivation of land and agricultural plants” (Z_{cp}) and “CO_2 sequestration” (Z_{cc}), which are implemented by the control subsystem based on data mining (H).

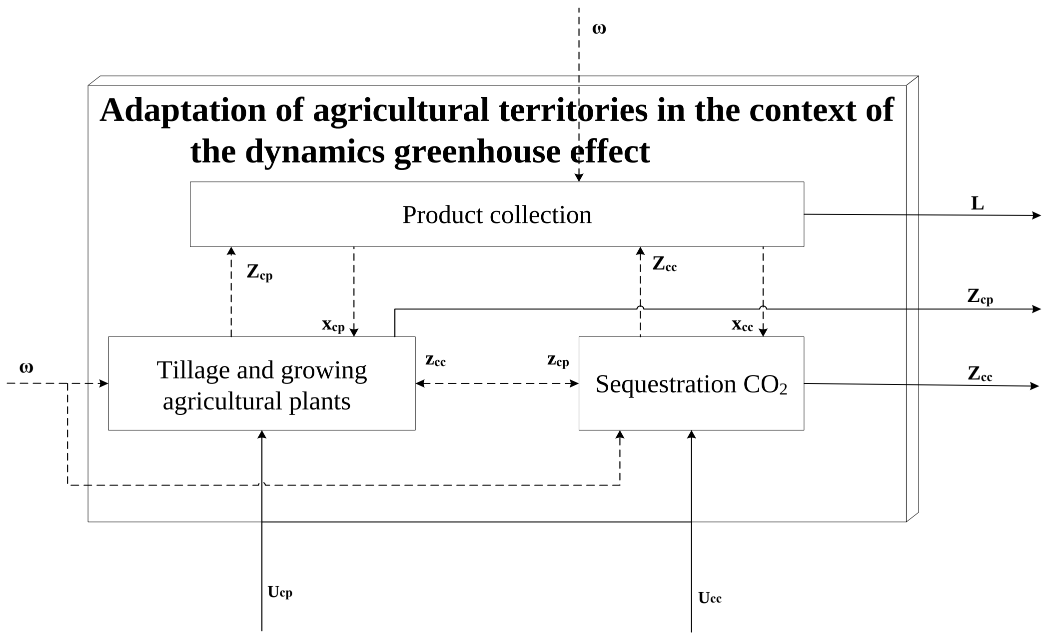

Figure 5 - A control object of an automated control system for the adaptation of agricultural areas under the changing greenhouse effect

Selected S_{oy} components perform the following mappings:

$$f_X : Z_{cp} * Z_{cc} * \omega \rightarrow X,$$

$$f_{cp} : x_{cp} * z_{cp} * \omega * U_{cp} \rightarrow Z_{cp},$$

$$f_{cc} : x_{cc} * z_{cc} * \omega * U_{cc} \rightarrow Z_{cc},$$

Thus, $f_{oy} = \{f_X, f_{cp}, f_{cc}\} -$ set., including the full range of cause-and-effect relationships that should be implemented by the models and algorithms described above. The corresponding structural model of the control object of the automated system for the adaptation of agricultural territories under the changing GHE is shown in Figure 5.

Conclusion

The paper presented the approaches to the construction and organization of the functioning of an automated control system for the adaptation of agricultural territories under the changing GHE, which will ensure an increase in productivity. A conceptual chart for zoning agricultural areas based on intelligent decision support using special models and algorithms is proposed. The authors have developed functional, structural models of automated control systems that differ from traditional control systems by the introduction of such mechanisms for the implementation of the control process as mathematical, simulation, situational models, appropriate software, as well as the introduction of a specialized subsystem - an intelligent decision support system at the level of which adaptation scenario models are formed. A conceptual and structural model of the automated control system for the class under study has been developed. The automated control system with the proposed structure can be used as a component of an intelligent network for managing the agricultural territories of the region. The results will primarily help to ensure a stable increase in yields and food security.

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